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WEATHER SUPPORT TO THE NASA DEEP SPACE NETWORK

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1. INTRODUCTION

Since February 1999, the NWS Spaceflight Meteorology Group (SMG) at the Johnson Space Center has been providing weather support on an experimental basis to NASA/JPL (Jet Propulsion Laboratory) for the Deep Space Network (DSN) antenna site at Goldstone, CA.

This paper outlines the evolution and development of SMG weather support and describes the Goldstone forecast product currently being disseminated as well as the next generation forecast product planned for future implementation.

2. BACKGROUND

The NASA Deep Space Network is operated by JPL, which in turn is managed by the California Institute of Technology. The DSN has three complexes of large antennas (34 meter and 70 meter diameter) at Goldstone, CA, Madrid, Spain, and Canberra, Australia.

The newly constructed worldwide network of 34 meter beamwaveguide antennas is being implemented for operation at a frequency of 32 GHz (Ka-band). Microwave propagation at this frequency is adversely affected to a significant degree by water vapor and liquid water particles (clouds and rain).

Scientists at JPL feel that with accurate forecasts of weather conditions at the DSN receiving sites, resulting microwave propagation conditions can also be forecast. Appropriate modifications to the telecommunications link can then be made to maintain an adequate signal-to-noise ratio thereby optimizing data return.

3. PRODUCT DEVELOPMENT

In mid 1998, SMG received a request from JPL for daily weather support for the Goldstone antenna site. In early December of that year, an SMG team was assembled to determine forecast requirements and develop an operations plan.

By early February 1999, a prototype forecast product was developed and an operations plan was implemented. The plan incorporates a combination of automated and manual procedures utilizing NCEP forecast guidance and requires only 10 to 20 minutes of forecaster time to prepare and disseminate to the customer at JPL.

4. PRODUCT DESCRIPTION, OPS PLAN

The product consists of an electronic spreadsheet template separated into surface and upper air sections. The surface section is filled out by the SMG forecaster after analyzing a suite of NCEP model products which are automatically displayed on the forecaster workstation by running a single batch file. (See Table 1, bold center portion). The forecaster inputs the model (Eta, AVN) in the command that executes the batch file. The forecaster then completes the spreadsheet and e-mails to the customer.

Model graphics displayed by the batch file were chosen from the NCEP BUFR dataset (Plummer, 1989). The Goldstone site has been added to the dataset through special request from SMG. Forecast guidance products generated by the batch file include the following:

1. Goldstone Precipitation meteogram
2. Goldstone Cloud meteogram
3. Goldstone RH meteogram
4. Goldstone forecast soundings
5. EDW, DAG surface obs, TAF's
6. EDW, DAG MOS products

Transparent to the SMG forecaster, the upper air files are automatically sent to the NASA public weather server by the same batch file using ftp. These files consist of raw upper air model data at 12 hour increments out to 48 hours. The data includes pressure (P), temperature (T), Dewpoint temperature (Td), and geopotential height (z) at each level. The customer can chose levels depending on the vertical resolution desired. Up to 33 levels are available in the Eta.

If intermediate forecast hours are required, the forecaster must run a separate batch file for each hour forecast. A corresponding upper air file for that hour is automatically generated and transferred to the ftp server while a forecast sounding is displayed for that hour on the forecaster workstation.

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The customer at JPL has access to the raw upper air files through the internet using a shared password. The surface and upper air data is then transferred by the user to a calculation spreadsheet which computes Absolute Humidity (AH) at each pressure level and liquid water content for each cloud layer. When the JPL spreadsheet is complete it will appear like the example in Table 1.

Table 1. Input Portion of Atmosphere Noise Temperature Calculation Spreadsheet.

SURFACE WX CLEAR SKY INPUTS				ANSWERS						
Frequency, GHz=		31.400			oxygen	wv	cloud	rain	total	
T,surface, degC=		see below		attn, dB	0.1090	0.0853	0.4961	0.3058	0.9961	EXACT
P,surface, mb=		see below		temp, K	6.572	5.439	29.767	18.345	51.885	EXACT
RH,surf, 0-1=		see below	feet v		^^^^^^^^APPROXIMATIONS^^^^^^^^					
HT,msl,km=		0.960	3149.8							
ELEV angle, deg=		90.000								
Location	**Goldstone**				**Pressure levels (mb)**					
Elevation	**3153 ft. MSL**				**Cloud layers (base feet AGL)**					
Issue Date	**2/11/00**									
Issue Time	**2215Z**									
FCST HR		**12**	**18**	**24**	**30**	**36**	**42**	**48**		
Valid Date		**2/12/00**	**2/12/00**	**2/12/00**	**2/12/00**	**2/13/00**	**2/13/00**	**2/13/00**		
Valid Time	**(GMT)**	**0000Z**	**0600Z**	**1200Z**	**1800Z**	**0000Z**	**0600Z**	**1200Z**		
Clouds	**(CLR, CLDY, Cirrus)**	**CLDY**	**CLDY**	**CLDY**	**CLDY**	**CLDY**	**CLR**	**Cirrus**		
Cloud1	**Base (ft. AGL)**		**5000**	**5000**	**5000**	**5000**				
Cloud2	**Base (ft. AGL)**	**15000**	**10000**	**10000**	**10000**					
Cloud3	**Base (ft. AGL)**	**25000**	**20000**	**20000**				**20000**		
Pcpn	**Begin (GMT)**		**0600**	**1200**						
	End (GMT)		**1200**	**1800**						
	Rate (mm/hr.)		**1**	**2**						
Surface	**T (F)**	**55**	**53**	**53**	**52.5**	**52**	**50.5**	**49**		
	Td (F)	**40**	**46**	**48**	**46.5**	**45**	**42.5**	**40**		
FCST HR		24	<copy/paste-special							
Valid Date		2/12/00	values from above							
Valid Time (GMT)		1200Z								
Clouds	(CLR, CLDY, Cirrus)	CLDY	cld top	lwc,g/m3	base,km	top,km				
Cloud1	Base (ft. AGL)	5,000	8000	0.2	1.5239	2.4383				
Cloud2	Base (ft. AGL)	10,000	13000	0.2	3.0479	3.9622				
Cloud3	Base (ft. AGL)	20,000	23000	0	6.0957	7.0101				
Pcpn	Begin (GMT)	1200								
	End (GMT)	1800	rain,km							
	Rate (mm/hr.)	2	1							
Surface	T (F)	53								
	Td (F)	48								

5. JPL APPLICATIONS

Table 1 was chosen to illustrate a particular cloudy/rainy period at Goldstone, which was verified by rain gauge measurements and water vapor radiometer (WVR) measurements made at the same location. The seven individual forecasts for the 48 hour period include weather conditions ranging from clear to three cloud layers and rain. The table shows the input portion of the spreadsheet used to calculate predicted atmosphere microwave noise temperatures from predicted weather parameters.

As can be seen, the forecast spreadsheet is imported as a whole into the calculation spreadsheet. The upper air values for 33 levels are imported into another portion of the spreadsheet (not shown). An absolute humidity profile is calculated from the T and Td values in the upper air file. For each specific forecast (e.g., 24-hr), the column containing the forecast values is copied just below, and from those values additional input values are calculated.

Since only the cloud base is presently given, the cloud top is calculated to be 3000 feet above the base. The base and top heights determine the temperature values within the cloud. The cloud microwave effect is strongly dependent on the temperature, with lower temperature clouds having a greater noise temperature contribution than warmer clouds.

A default liquid water content of 0.2 g/m^3 was chosen for all cloud layers, except for those with bases higher than 20,000 feet AGL, which are assumed to consist of ice particles and which have no microwave effect at our frequency of interest. For comparison with WVR measurements, a calculation frequency of 31.4 GHz was chosen, as opposed to the DSN operating frequency of 32 GHz. The frequency difference has only a slight effect on actual microwave noise effects. A rain height of 1 km above the ground was assumed, and it was also assumed that the rain rate was constant with height.

Figure 1 shows a plot of measured cumulative rainfall at the Goldstone WVR site during the period February 10-14, 2000. Note that 0.2 inches of rain fell just after 12Z on 2/12. Although the time and accumulation resolution is poor, the rainfall rate was probably somewhere between 1 and 2 mm/hr, which agrees with the forecast values.

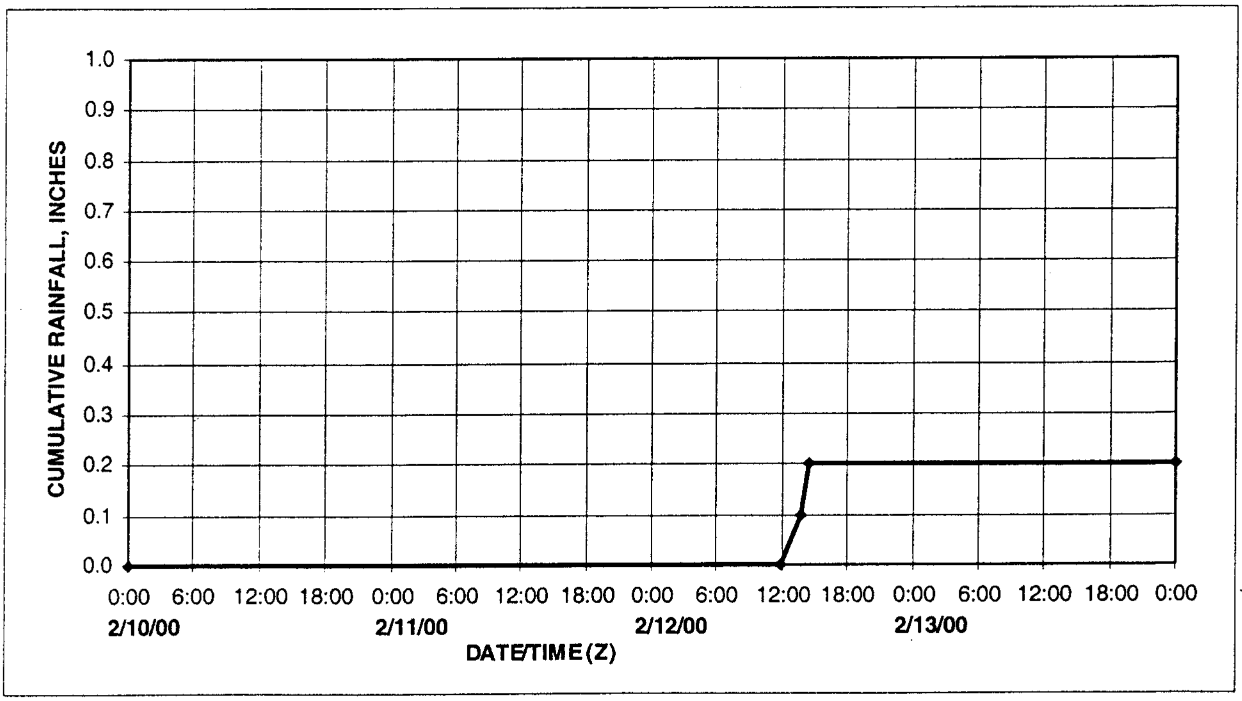

FIGURE 1. Cumulative Rainfall at Goldstone WVR site, February 10-14, 2000.

Figure 2 shows noise temperatures calculated for the seven individual forecasts for issue date 2/11/00 (Table 1). The calculations are done using the method of radiative transfer. Algorithms for the attenuation values of oxygen, water vapor, clouds, and rain are given in Ulaby (1981). The calculated values are plotted against measured WVR values for the four day period February 10-14, 2000.

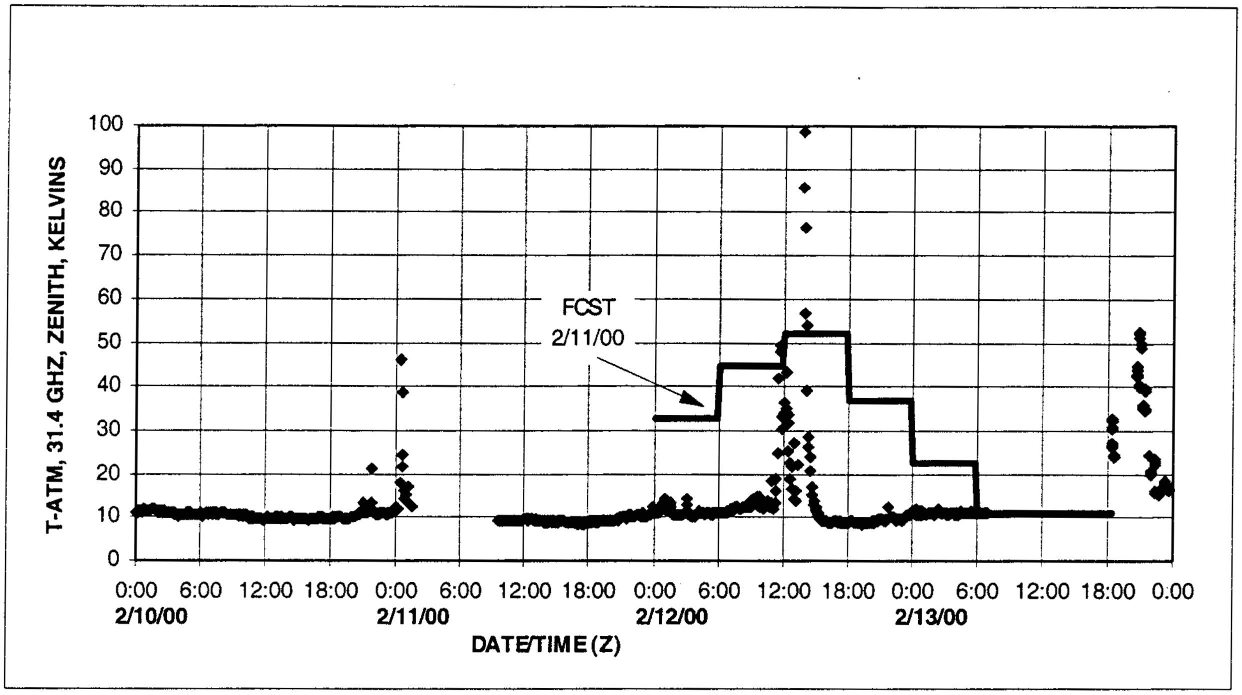

FIGURE 2. Zenith Atmosphere Noise Temperatures at 31.4 GHz Calculated from Goldstone Weather Forecasts, Plotted Against WVR Measured Noise Temperatures.

An atmosphere noise temperature increase of 20 K would begin to have a serious effect on a Ka-band telecommunication link. If this could be accurately forecast, a possible modification to the link could be made, such as lowering the spacecraft downlink data rate for the period of predicted impaired communications.

The characteristic of the WVR values is that there is clear sky and moderate cloudiness prior to 12Z on 2/12. Then at 12Z, there is an abrupt increase in noise temperature to 50 K, believed to be due to a rapid increase of cloud liquid water content, thickness, or both, but not due to rain. The distinctive spike at 14Z on 2/12 is due to rain, and agrees exactly with the measurements seen in the rain gauge values of Figure 1. The apparent cloudiness at 00Z on 2/11 was predicted in a 36-hour forecast issued on 2/9/00.

Clearly, the cloud model still overestimates the noise temperature during the period from 00Z 2/12 to 12Z 2/12. The mixture of cloud and rain forecast for 12Z on 2/12 gives 40-50 Kelvins, which agrees with the WVR values. During the rain event at 14Z on 2/12, the calculations greatly underestimate the 100 Kelvin rain effect. The time of onset of cloudy/rainy conditions was very well predicted, and a forecast of this type would be quite useful for telecommunications purposes, despite the limitations of the noise temperature modeling process.

Future work will involve implementing a more sophisticated cloud model, including cloud coverage, liquid water content, and base and top heights. The rainfall model should be improved to better define the top of the rain and a distribution of rain rate with height. Under rainy conditions, however, the microwave link is so degraded that a highly accurate rainfall prediction would be of little help, except for being able to note the onset of degraded spacecraft communications.

6. FUTURE UPGRADES

Development of an upgraded Goldstone forecast product has been ongoing at SMG since the implementation of daily weather support in February 1999. A First Guess Cloud Forecast (FGCF) product (Oram, 2000) is now available to replace the current spreadsheet being disseminated daily to JPL. The FGCF is similar to the existing spreadsheet but produces more detail and requires no additional calculations to arrive at the desired parameters. The FGCF utilizes NCEP Grid data but may be modified in the future to use BUFR data. Algorithms from the Local Analysis and Prediction System (LAPS) (McGinley and Albers 1991, Albers et. al 1996) and the Automated Weather Information Processing System Forecast Preparation System (AFPS) (Ramer, 1993) are used to generate the following parameters for up to 4 cloud layers:

1. Cloud amount and type
2. Cloud base height
3. Cloud top height
4. T, z, AH, liquid water content at each P level
5. Surface rainfall rate

When implemented, this product will be e-mailed to JPL as a comma separated variable (csv) file. The customer can then import the file directly into a spreadsheet similar to Table 2 without additional calculations. This will enable JPL to utilize the data in a much more timely and effective manner without increasing the SMG workload.

An electronic spreadsheet interface will allow forecaster input and editing capability. When the FGCF interface is ready for implementation, the present batch file will be edited to allow for automatic generation of the FGCF. This will eliminate the step that transmits (ftp) raw upper air data files to the NASA Pubic Weather Server. The automatic display of forecast guidance will be retained in the batch file to assist in forecaster evaluation.

7. CONCLUSION

Although only limited verification has been performed by JPL on actual forecast data, preliminary test results are encouraging. Nearly 15 months of daily forecasts are now available for study. It is hoped that with additional forecasts during the remainder of 2000, there will be sufficient test data to determine the value of realtime operational, weather forecasts to DSN telecommunications operations at Ka-band.

In addition, SMG is planning to implement the First Guess Cloud Product (FGCF) in July of 2000 which will provide additional forecast detail and greatly reduce the JPL workload.

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